E C O N O M I C S B U L L E T I N

London−type congestion tax with revenue−recycling

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Abstract

Road pricing in London attracts a great deal of interest. A challenging aspect of the London scheme is that congestion tax revenue is used to upgrade public transit networks. Although Parry and Bento (2001) show that the total social surplus would increase if congestion tax revenues are used to cut labor taxes, political difficulties exist in implementing revenue−recycling between congestion taxes and labor taxes. Given such political difficulties, the London scheme seems to be very attractive. In this paper, we develop a model that can expressly deal with the London−type revenue−recycling between congestion tax and investment in public transit, and analyze its effects.

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1. Introduction

Road pricing in London attracts a great deal of interest. A challenging aspect of the London scheme is that revenue from congestion tax is used to upgrade public transit networks. Recently, Parry and Bento (2001) showed that the total social surplus would increase if revenue from congestion tax is used to cut labor taxes. However, political difficulties exist in implementing the scheme advanced by Parry and Bento (2001). First, a congestion tax would usually be a "local" tax, which is collected at the regional level, such as a city, although labor taxes would be a "national" tax, collected at a national level. Such an actual hierarchical system of tax collection would make it difficult to implement the revenue-recycling scheme between congestion taxes and labor taxes. Second, even if the authorities solve the tax administration problem, the issue of residents' support for a congestion tax remains. In order to get support from residents who pay congestion taxes, the congestion tax scheme must be understood by them. In this regard, it would be much easier to use congestion tax revenue to improve the public transit system than to use the revenue to decrease labor taxes.

Considering such practical difficulties to implement revenue-recycling between congestion taxes and labor taxes, the London scheme seems to be very attractive. However no simple economic model currently exists to analyze the London congestion tax scheme. Thus, in this paper we develop a model that can deal explicitly with the London-type congestion tax with revenue-recycling and analyze its effects.

The rest of the paper is organized as follows. In Section 2, we build a model. In Section 3, we analyze the effects of the London-type congestion tax scheme with revenue-recycling on both transport demand and the social surplus to derive the optimal congestion tax. In Section 4, we conclude present analysis and consider possible future extensions.

2. The Model

Consider the following situation. A representative consumer who lives in the surrounding area to the CBD demands the composite consumer good z, and the transport services to the CBD, x^1 and x^2. x^1 is road transport for which congestion tax is levied, and x^2 is public transit that receives congestion tax revenue in the form of additional investment. This setup would be realistic provided that the transport authority wants to divert traffic from road transport to public transit due to a lower social marginal cost of the latter. However, our argument is applicable if x^1 and x^2 are substitutable roads in a road network and the transport authority finances the investment costs of x^2 using the toll revenues from x^1. The essential point is that x^1 is taxed and x^2 receives the tax revenue in the form of investment. In this paper, both x^1 and x^2 are congestion-prone. For the sake of simplicity, traffic from the CBD to the surrounding area of the CBD, that is the reverse direction of traffic, is ignored.

The utility function of a representative consumer is:

$$U = z + u(x^1, x^2), \tag{1}$$

which is assumed to be strictly concave. The quasi-linear utility function of (1) implies that income effects are ignored. This simplifying assumption would be justified if transport's expenditure share is low. The price of the composite consumer good, z, is normalized to unity. The generalized prices of x^1 and x^2, which include time costs, are p^1 and p^2.

The budget constraint is:

$$y = z + p^1x^1 + p^2x^2 \qquad (2)$$

where y is full income. In this paper, labor hours are assumed to be fixed. This implies that labor market distortions are ignored.

A representative consumer maximizes his or her utility, (1), subject to the budget constraint, (2). The maximization yields the following first order conditions:

$$u_{x^1} = p^1, \qquad (3)$$

$$u_{x^2} = p^2, \qquad (4)$$

where the subscripts denote partial derivatives throughout the paper. From (3) and (4), we derive the demand functions of $x^1(p^1, p^2)$ and $x^2(p^1, p^2)$, which satisfy

$$\frac{dx^1}{dp^2} = \frac{dx^2}{dp^1} = -u_{x^1x^2}. \qquad (5)$$

In this paper, x^1 and x^2 are assumed to be substitutes and consequently, $\frac{dx^1}{dp^2} = \frac{dx^2}{dp^1} = -u_{x^1x^2} > 0$, which implies $u_{x^1x^2} < 0$. For our purpose, x^1 and x^2 need not be perfect substitutes for which Wardrop (1952) equilibrium applies.

The authorities (the city of London or Tokyo, for instance) impose congestion tax, τ, for road transport, x^1. The price of road transport is then

$$p^1 = \tau + c^1(x^1), \qquad (6)$$

where $c^1(x^1)$ is the generalized price of road transport net of congestion tax and $c^{1\prime}(x^1) > 0$.

The price of public transit (or the subsidized transport service), x^2, is

$$p^2 = c^2(x^2, I), \qquad (7)$$

where $c^2(x^2, I)$ is the generalized price of public transit and I is monetized investment. We assume that the congestion of public transit causes delays, that is, $c^2_{x^2} \geq 0$ and investment relieves the delays to lower its generalized costs, that is, $c^2_I < 0$. We assume there is no possibility of a congestion tax for public transit.

Congestion tax revenue is denoted by R, which is assumed to be used as the investment for public transit, I. Thus, the following equation holds

$$I = R = \tau x^1. \qquad (8)$$

3. Analysis

3.1 The effects of the congestion tax on transport with revenue-recycling

In Subsection 3-1, we examine the effects of congestion tax, τ, on transport demand, x^1 and x^2 with revenue-recycling. Totally differentiating and rearranging (3), (4), and (6)-(8), we obtain $x^1(\tau)$ and $x^2(\tau)$, which satisfies:

$$\frac{dx^1}{d\tau} = |D|^{-1}\left\{(u_{x^2x^2} - c^2_{x^2}) - c^2_I u_{x^1x^2} x^1\right\} < 0 \qquad (9)$$

$$\frac{dx^2}{d\tau} = \left|D\right|^{-1}\left[-u_{x^1x^2} + c_I^2\left\{(u_{x^1x^1} - c^{1\prime})x^1 + \tau\right\}\right] \tag{10}$$

where

$$\begin{aligned}\left|D\right| &= (u_{x^1x^1} - c^{1\prime})(u_{x^2x^2} - c^{1\prime}) - u_{x^1x^2}(u_{x^1x^2} - \tau c_I^2) \\ &= u_{x^1x^1}u_{x^2x^2} - (u_{x^1x^2})^2 - c^{1\prime}(u_{x^2x^2} - c_{x^2}^2) - c_{x^2}^2 u_{x^1x^1} + \tau c_I^2 u_{x^1x^2} > 0\end{aligned}$$

from the strict concavity of utility function, $c^{1\prime} > 0$, $c_{x^2}^2 > 0$, $c_I^2 < 0$, and $u_{x^1x^2} < 0$.

We begin by looking at $\frac{dx^1}{d\tau}$. From (9), we know that a change in τ yields two effects. Congestion tax for road transport makes its generalized price relatively higher than that for public transit. The demand for road transport decreases by this effect, which is represented by the term of $\left|D\right|^{-1}(u_{x^2x^2} - c_{x^2}^2) < 0$ in (9). This effect is caused by the congestion tax on x^1 itself; the effect exists whether a revenue-recycling mechanism is adopted or not. A revenue-recycling scheme increases public transit investment, which lowers public transit's generalized price. This effect also works to make the generalized price of road transport relatively higher and consequently, the demand for road transport is further decreased. This effect through revenue-recycling is represented by the term of $\left|D\right|^{-1}(-c_I^2 u_{x^1x^2} x^1) < 0$ in (9). Since both effects work to decrease road transport, we know that a congestion tax with revenue-recycling unambiguously decreases road transport demand.

Next, we look at $\frac{dx^2}{d\tau}$. Congestion tax has an effect to increase public transit demand, because it makes the generalized price of public transit relatively lower than that of road transport. This effect is represented by the term of $\left|D\right|^{-1}(-u_{x^1x^2}) > 0$ in (10). This effect stems from the congestion tax on x^1 itself and exists whether a revenue-recycling mechanism is adopted or not. The first effect of revenue-recycling is represented by $\left|D\right|^{-1}\left\{c_I^2(u_{x^1x^1} - c^{1\prime})x^1\right\} > 0$ in (10). Revenue-recycling increases public transit investment and lowers its generalized price. Thus, public transit demand is increased by this effect. However, the second effect of revenue-recycling, $\left|D\right|^{-1}(c_I^2\tau) < 0$ in (10), makes the sign of $\frac{dx^2}{d\tau}$ ambiguous. An increase in congestion tax decreases the demand for road transport, and reduces the revenues from congestion tax *ceteris paribus*. This second effect of revenue-recycling decreases investment in public transit and raises its generalized price. Thus, this second effect works to counteract the first effect of revenue-recycling. Whether the first effect outweighs the second effect or not depends on the size of τ and $(c^{1\prime} - u_{x^1x^1})x^1$. Usually the second effect would be minor and the first effect would be stronger than the second; the net effect of revenue recycling works to increase public transit demand. In this case, the overall effect of an increase in the congestion tax on x^2 is positive, that is, $\frac{dx^2}{d\tau} > 0$.

3.2 The effects of the congestion tax on the social surplus with revenue-recycling

In Subsection 3-2, we examine the effects of the congestion tax, τ, with revenue-recycling on the social surplus. From (1), (2), and (6)-(8), the total social surplus, SS, can be formulated as

$$\begin{aligned} SS &= U + p^1x^1 - c^1(x^1)x^1 + p^2x^2 - c^2(x^2, I)x^2 - I \\ &= y + u(x^1, x^2) - c^1(x^1)x^1 - c^2(x^2, \tau x^1)x^2 - \tau x^1. \end{aligned} \tag{11}$$

Totally differentiating (11) with respect to τ yields

$$\begin{aligned} \frac{dSS}{d\tau} &= (\tau - c^{1\prime}(x^1)x^1)x^1_\tau - c^2_{x^2}x^2x^2_\tau - c^2_I x^2 I_\tau - I_\tau \\ &= (p^1 - MC^1)x^1_\tau + (p^2 - MC^2)x^2_\tau + (-c^2_I x^2 - 1)I_\tau, \end{aligned} \tag{12}$$

where $MC^1 \equiv c^1 + c^{1\prime}x^1$ and $MC^2 \equiv c^2 + c^2_{x^2}x^2$.

The first term of (12), $(p^1 - MC^1)x^1_\tau$, represents a change in the social surplus that congestion tax causes through a change in the demand for road transport. If roads are heavily congested and, consequently, road transport's generalized price is lower than its marginal cost, this term is positive from (9). The second term of (12), $(p^2 - MC^2)x^2_\tau$ shows a change in the social surplus that a congestion tax produces via a change in the demand for public transit. If public transit is not heavily congested and consequently, its generalized price is higher than its marginal cost and $x^2_\tau > 0$, this term is also positive. (Remember that $x^2_\tau > 0$ holds true in usual cases where the net effect of revenue recycling works to increase public transit demand.) The first and second terms of (12) imply that an increase in congestion tax is welfare-improving as long as road transport congestion is heavy and public transit congestion is light.

The third term of (12), $(-c^2_I x^2 - 1)I_\tau$, represents the effect caused by revenue-recycling. We call this effect the "revenue-recycling effect" after literature on "double dividend" of environmental taxes. Denoting the elasticity of road transport demand with respect to congestion tax by $\varepsilon \equiv -\frac{x^1_\tau \tau}{x^1}$, I_τ can be rewritten as $I_\tau = x^1(1-\varepsilon)$. Thus, we obtain $I_\tau > 0$ if $\varepsilon < 1$. It would be reasonable to assume $\varepsilon < 1$ throughout the paper. Thus, the revenue-recycling effect is positive and works to increase the social surplus as long as $-c^2_I x^2 > 1$, which means that the social benefit from investment in public transit outweighs its investment cost. Obviously, revenue-recycling will not always work to increase the social surplus; for example, if $-c^2_I x^2 < 1$, revenue-recycling works to lower the social surplus. This is because a lump-sum transfer is socially preferred if the social benefit from investment in public transit is smaller than its investment cost.

3.3 Optimal congestion tax with revenue-recycling

Setting (12) equal to zero, the optimal congestion tax is derived as

$$\tau = c^{1\prime}x^1 + \frac{x^2_\tau}{x^1_\tau}c^2_{x^2}x^2 - \frac{(-c^2_I x^2 - 1)I_\tau}{x^1_\tau}. \tag{12}$$

The first term of the right-hand side of (12) is the marginal congestion cost. If the model was the simple first-best model, the optimal congestion tax would be equal to the marginal congestion cost. Under our setup, however, there are two additional effects which change the first-best result.

The second term of the right-hand side of (12) stems from non-optimal pricing for public transit, which is caused by the assumption that congestion tax is not levied on public transit. A congestion tax for road transport must be set to take into account the subsequent effects on public transit congestion. We hereafter call the second term of the right-hand side of (15) "congestion spill-over effect" after Verhoef et al. (1996). A congestion spill-over effect arises because the congestion tax on a certain part of the transport network transfers the congestion to another part of the transport network. In our normal context where a congestion tax increases the demand for public transit, where $x_\tau^2 > 0$, the congestion spill-over effect is negative and works to lower the optimal congestion tax.

The third term of the right-hand side of (12) is the effect of revenue-recycling on congestion. If $-c_I^2 x^2 > 1$, revenue-recycling works to increase the optimal congestion tax. In such a case, higher congestion tax than the first-best level is socially justified, because transfer via revenue recycling is socially desirable as compared with lump-sum transfer.

The relative magnitude of any congestion spill-over effect and revenue-recycling effect determines whether the optimal congestion tax is larger than the marginal congestion cost or not. Two special cases are useful to obtain some insight.

First, in the case where public transit is not congested, that is, $c_{x^2}^2 = 0$, (12) is reduced to

$$\tau = c^{1\prime} x^1 - \frac{(-c_I^2 x^2 - 1) I_\tau}{x_\tau^1} > c^{1\prime}(x^1) x^1 \quad \text{if} \quad -c_I^2 x^2 > 1. \tag{13}$$

If there is no congestion spill-over effect, the optimal congestion tax is higher than the marginal congestion cost, provided revenue-recycling is socially preferable to lump-sum transfer.

Second, if there is no revenue-recycling effect, investment in public transit, I, is fixed and accordingly, $c_I^2 = I_\tau = 0$. In this case, (12) is reduced to

$$\tau = c^{1\prime} x^1 + \frac{x_\tau^2}{x_\tau^1} c_{x^2}^2 x^2 < c^{1\prime} x^1, \tag{14}$$

(Note also that $x_\tau^2 > 0$ unambiguously holds in the case of $c_I^2 = 0$ from (10)). (14) is basically the same as (14) of Van Dender (2004) and demonstrates that the optimal congestion tax is lower than the marginal congestion cost by the congestion spill-over effect. If $u_{x^1 x^1} = u_{x^2 x^2} = u_{x^1 x^2}$, that is, the demand for road transport and that for public transit are perfect substitutes, rearranging (14) using (9) and (10) yields

$$\tau = c^{1\prime} x^1 - c_{x^2}^2 x^2 \left(\frac{-u_{x^1 x^1}}{c_{x^2}^2 - u_{x^1 x^1}} \right), \tag{15}$$

which corresponds to (2) of Verhoef et al. (1996).

4. Conclusion

In this paper, we analyze a congestion tax scheme with revenue recycling between road transport and public transit. The main results are as follows:

(i) the demand for road transport, for which congestion tax is levied, decreases;

(ii) the demand for public transit, which receives revenues in the form of additional investment, is increased in usual cases where the net effect of revenue recycling works to increase the demand for public transit;

(iii) a congestion tax with revenue-recycling works to increase the total social surplus if the social benefits from investment in public transit exceed its investment cost; and

(iv) revenue-recycling works to raise the optimal congestion tax if the social benefit from investment in public transit is higher than its investment cost.

Our analysis has been conducted under the simplest possible model. We would need various extensions to apply our analysis to an actual situation. For instance, revenue-recycling in this paper is somewhat extreme in that all congestion tax revenue is applied to public transit in the form of additional investment. In reality, some of this revenue would be used to invest in road transport on which a congestion tax is imposed. How to determine the appropriate intensity of revenue-recycling, with a given level of congestion tax, also remains unsolved. These lines of research are deferred to future studies.

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